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# Relationships between Total Suspended Particulate, Sulfate, and Respirable Suspended Particulate Concentrations. Analysis of Data Collected in New York City

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## Analysis of Data Collected in New York City

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# RELATIONSHIPS BETWEEN TOTAL SUSPENDED PARTICULATE, SULFATE, AND RESPIRABLE SUSPENDED PARTICULATE CONCENTRATIONS
## Analysis of Data Collected in New York City

by

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## ABSTRACT

Two years of data for daily total suspended particulate, sulfate, and respirable suspended particulate concentrations measured at four stations in the New York City area are statistically analyzed. To show the variability of each pollutant data set, the mean, median, and 16th and 84th percentile values of concentration of each pollutant are summarized. To demonstrate the spatial representativeness of the concentrations of individual pollutants, the daily (24-hour) concentrations at pairs of stations were compared and correlation coefficients determined. Results indicated that sulfate concentrations varied on an area-wide basis while the concentration of respirable suspended particulates at the four stations appeared to depend on local conditions.

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# SECTION 1

## INTRODUCTION

Measurements of the concentrations of air pollutants are generally made at widely separated sampling sites and it is assumed that each sample is representative of a large area surrounding the sampling site. To those trying to correlate variations in meteorological phenomena with variations in concentrations, the spatial representativeness of the pollutant concentration is significant. The reason for the significance is that the meteorological observations are frequently taken at sites which are not in the same general area as the sampling site; for any pollutant-meteorological correlations to be meaningful both sets of observations must represent conditions in a common area.

In order to obtain an estimate of the spatial representativeness of measurements of total suspended particulate (TSP), sulfates ($SO_4$), and respirable suspended particulates (RSP), two years of daily air quality data from a four-station network in the New York City area have been analyzed in detail. Since all of these pollutants are particulates and could be interrelated, the correlation coefficients of pairs of pollutants were also determined. The concentration data are summarized for the entire sampling period (annual = 2-year composite) and for the calendar quarters for the year (first quarter includes January, February, and March).

## SECTION 2

## CONCLUSIONS

Analyses of the TSP, $SO_4$ and RSP data of July 1, 1974 to June 30, 1976, for four stations in the New York City area, were used to determine the distribution of the pollutant concentrations. The correlation coefficients of pairs of pollutants were also determined.

Sulfate concentrations, even though they showed large differences in average concentrations and in the distribution of concentrations among the stations, varied on an area-wide basis (the largest separation between stations was 125 km). An $SO_4$ observation at one site was generally representative of the area.

Respirable suspended particulate concentrations among the four sites, even though two of them were only 10 km apart, varied independently. High RSP concentrations were more dependent on local rather than distant or regional sources; the concentrations would have varied more uniformly if distant or regional sources were the cause of the RSP concentrations.

The variations in TSP concentrations among the four sites were more consistent than those shown in RSP concentrations and less consistent than those shown in $SO_4$ concentrations. However, there was no obvious indication that either local or distant sources were important in determining when high TSP concentrations would occur.

At the individual sites, on an annual basis, TSP and $SO_4$ were fair surrogates of one another (correlation coefficients of 0.75). Total suspended particulate and RSP, and RSP and $SO_4$ were not as good of substitutes for one another (correlation coefficients near 0.65) as were TSP

and $SO_4$. In the second and third quarters the average concentrations of TSP, $SO_4$, and RSP were higher than they were for the year; in those quarters all three pollutants were better surrogates for one another than they were on an annual basis.

## SECTION 3

## SOURCE OF SAMPLING DATA, INSTRUMENTS, SITES, RECORDS, AND ANALYSES

From January 1974 through June 1976 the Community Health Air Monitoring Program (CHAMP) of the United States Environmental Protection Agency (EPA) operated a four-station air quality sampling network in the New York City area. Among the data collected were daily 24-hour samples of TSP, $SO_4$, and RSP. Each 24-hour sample was collected and analyzed in accord with the recommended procedures of EPA[1], but the filters were changed at 11 a.m. Eastern Standard Time (normally 24-hour samples are collected from midnight to midnight). The TSP and $SO_4$ were collected with high volume air sampling equipment and the RSP samples utilized a device known as a "cyclone"[1].

The locations of the four sampling sites are shown in Figure 1. A more precise location of each of the stations in New York City is shown in Figure 2. The shortest distance between sites was 10 km (between Brooklyn and Queens), while the Riverhead site was 125 km east of New York City. The Queens and Brooklyn sites were near the southern edge of the metropolitan area (a short distance from the Atlantic Ocean) while the Bronx site was surrounded by an extensive built-up area. The Riverhead site was considered a relatively clean site outside the major influence of New York City.

The listings of the data were supplied by the Health Effects Research Laboratory of EPA. The listings show the 24-hour concentration of each pollutant for the day on which the sample was removed from the collector. About 80 percent of the data for June 1974 were missing, so the period selected for analysis was July 1, 1974 through June 30, 1976. There were occasional days after June 30, 1974 when data for one or more pollutants were missing and the cyclone instrument went out of service in late

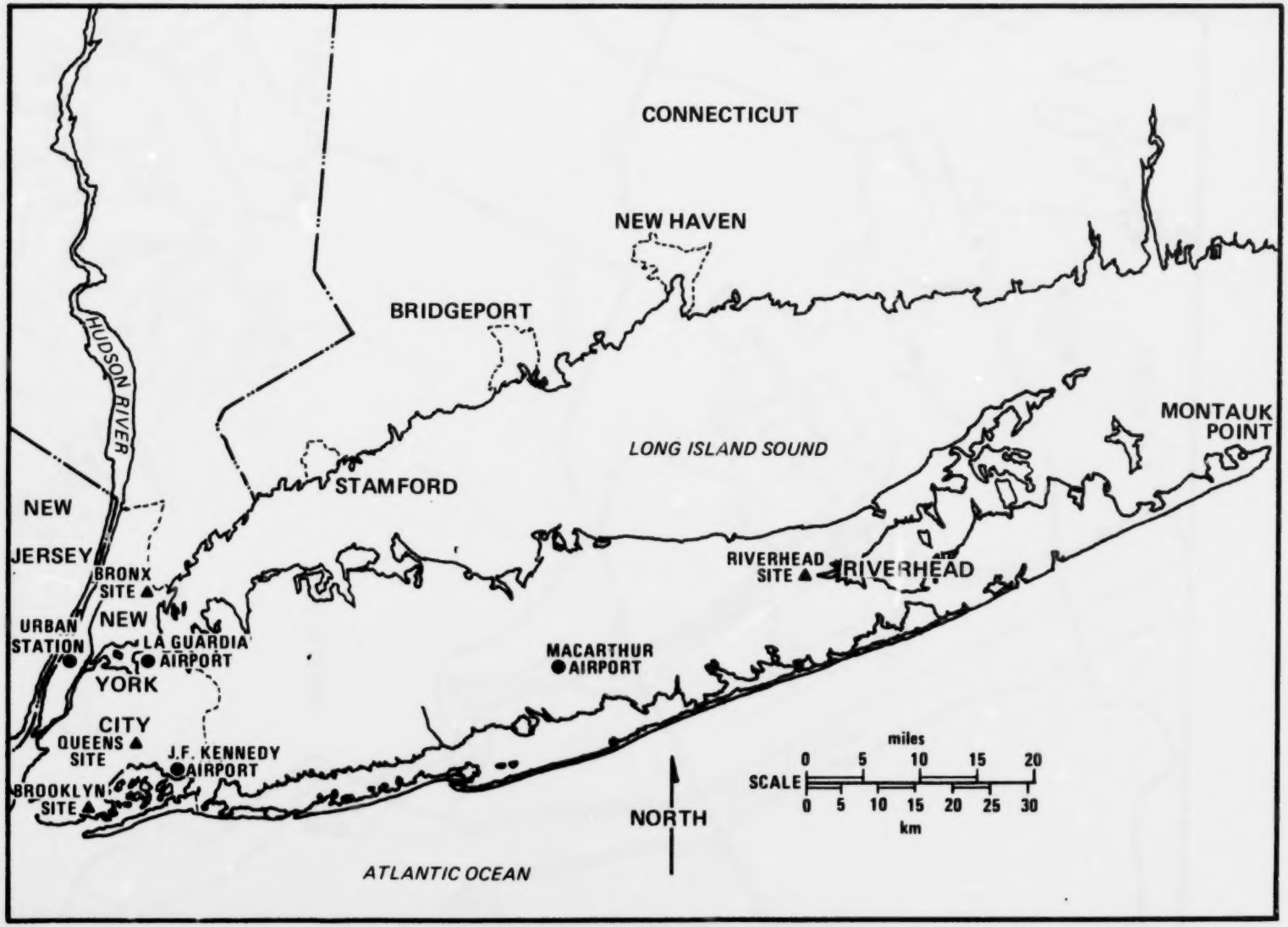


Figure 1. CHAMP stations in the New York City area.

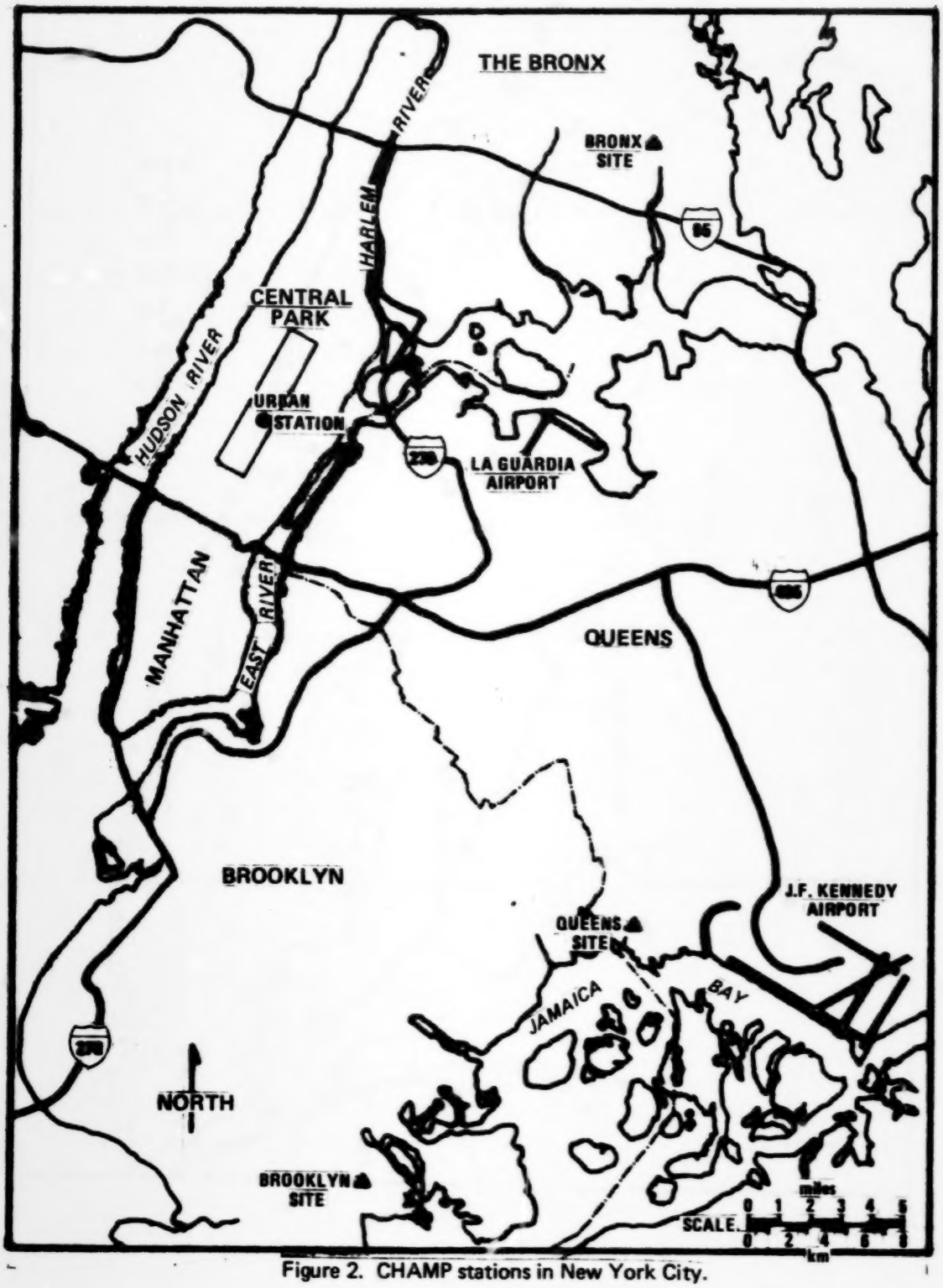


Figure 2. CHAMP stations in New York City.

February 1976. Sulfate and TSP data were available for all stations for more than 90 percent of the days and RSP data were available for more than 85 percent of the days.

In order to characterize the population distribution of concentrations of the individual pollutants at each site, the concentrations of each pollutant at each site were statistically analyzed. There are many ways of summarizing the information contained in a data set. The two most widely used in a statistical analysis are the mean and a measure of the variability of the probability distribution[2]. For this report the mean (average), median (50th percentile), and 16th and 84th values of concentrations were determined for the entire period and each quarter of the year. When the distribution for values is normal the mean and median are approximately the same, and the 16th and 84th percentiles are each one standard deviation from the median. To demonstrate the spatial representativeness of the concentrations of individual pollutants, the daily concentrations at pairs of stations were compared and correlation coefficients for the entire sampling period and each quarter of the year were calculated. To show the interrelationship of the concentrations of the particulate pollutants, pairs of observations at the individual sites were compared and annual and quarterly correlation coefficients calculated.

## SECTION 4

## RESULTS

### ANNUAL AND QUARTERLY AVERAGE, MEDIAN, AND 16TH AND 84TH PERCENTILE OF 24-HOUR CONCENTRATIONS

#### Total Suspended Particulate Concentrations

The average (mean), median, and 16th and 84th percentile values of 24-hour TSP concentrations for each of the four sites for the year and each quarter are listed in Table 1. The primary 24-hour National Ambient Air Quality Standard (NAAQS) for TSP is 260 $\mu g/m^3$ (not to be exceeded more than once a year). The value 260 $\mu g/m^3$ was exceeded on only one occasion at only one site during the two years.

TABLE 1. AVERAGE 24-HOUR CONCENTRATIONS, TSP ($\mu g/m^3$) AND PERCENTILES (16TH/50TH/84TH), CHAMP STATIONS, NEW YORK CITY AREA, JULY 1974-JUNE 1976

| Period of Year | Station | | | |
|---|---|---|---|---|
| | Riverhead | Queens | Brooklyn | Bronx |
| Annual Average | 35 | 51 | 59 | 60 |
| Percentiles | 18/30/50 | 28/45/73 | 35/53/81 | 29/54/90 |
| 1st Quarter Average | 32 | 46 | 51 | 57 |
| Percentiles | 18/29/43 | 29/43/63 | 33/47/70 | 28/46/88 |
| 2nd Quarter Average | 37 | 51 | 58 | 66 |
| Percentiles | 19/32/53 | 29/43/71 | 34/53/79 | 33/60/94 |
| 3rd Quarter Average | 38 | 56 | 68 | 62 |
| Percentiles | 20/33/53 | 27/50/88 | 42/62/95 | 35/58/88 |
| 4th Quarter Average | 30 | 51 | 56 | 56 |
| Percentiles | 15/27/44 | 28/45/74 | 34/49/76 | 25/49/86 |

The annual average 24-hour TSP concentrations (Table 1) show that the Riverhead concentrations were considerably lower than those at the three New York City sites. The annual averages and medians show that the Brooklyn and Bronx sites had comparable concentrations but the 16th and 84th percentiles disclose that the concentrations had a much larger range at the Bronx site. Although the Brooklyn site had a higher annual average concentration than the Queens site, the range of values between the 16th and 84th percentiles was practically the same; the distribution patterns were similar but centered on different medians. The data for the quarters show that the Riverhead site consistently had the lowest average concentrations, and in the City the Queens site had the lowest average concentrations. In three of the four quarters the Bronx had the highest average 24-hour concentration while the Brooklyn site had the highest average concentrations in the third quarter. Three of the four sites had their highest concentrations in the third quarter and the second highest concentrations in the second quarter at the Bronx site the highest average concentrations occurred in the second quarter. The percentile data for the quarters show that the smallest difference between the 16th and 84th percentiles was 25 $\mu g/m^3$ (Riverhead in the first quarter) and the highest was 61 $\mu g/m^3$ (Queens in the third and the Bronx in the second and fourth quarters). The differences were always 25 $\mu g/m^3$ or greater and were frequently twice as great at sites in the City.

## Sulfate Concentrations

The 24-hour average, median, and 16th and 84th percentile values of $SO_4$ concentrations for each site for the year and each quarter are listed in Table 2. There is no NAAQS for $SO_4$ but concentrations as low as 10 $\mu g/m^3$ (24-hour average) have been associated with adverse health effects in preliminary epidemeological studies[3]. Since there is no other documentation on possible hazardous $SO_4$ concentrations, 10 $\mu g/m^3$ is used as a reference value. The annual average concentration at all three New York City sites exceeded 9 $\mu g/m^3$ and the 84th percentile for the year exceeded 10 $\mu g/m^3$ at all four sites; 24-hour $SO_4$ concentrations exceeding 10 $\mu g/m^3$ occurred frequently.

TABLE 2. AVERAGE 24-HOUR CONCENTRATIONS, $SO_4$ ($\mu g/m^3$) AND PERCENTILES (16TH/50TH/84TH), CHAMP STATIONS, NEW YORK CITY AREA, JULY 1974-JUNE 1976

| Period of Year | Station | | | |
|---|---|---|---|---|
| | Riverhead | Queens | Brooklyn | Bronx |
| Annual Average | 7.5 | 9.2 | 9.7 | 9.4 |
| Percentiles | 3.6/6.4/10.7 | 4.7/7.7/13.2 | 5.2/8.4/13.5 | 4.7/8.0/14.0 |
| 1st Quarter Avg. | 7.0 | 8.3 | 8.8 | 8.7 |
| Percentiles | 4.3/6.6/9.4 | 5.3/7.9/11.6 | 5.5/8.4/12.5 | 5.2/7.9/12.5 |
| 2nd Quarter Avg. | 7.9 | 9.5 | 9.5 | 10.0 |
| Percentiles | 3.8/6.3/11.3 | 4.8/7.9/13.6 | 5.2/8.1/13.5 | 4.9/8.1/14.6 |
| 3rd Quarter Avg. | 9.1 | 10.7 | 11.8 | 11.0 |
| Percentiles | 3.2/6.7/15.3 | 4.3/8.7/16.5 | 5.2/10.2/16.8 | 4.7/9.6/18.4 |
| 4th Quarter Avg. | 6.2 | 8.1 | 8.7 | 8.0 |
| Percentiles | 3.4/5.5/9.0 | 4.5/7.1/11.7 | 5.0/7.9/12.6 | 4.2/7.1/12.0 |

The lowest 24-hour average concentrations on an annual basis and in each quarter, as shown in Table 2, occurred in Riverhead. The Brooklyn site had the highest average $SO_4$ concentrations on an annual basis and in all quarters but the second, when the highest concentrations occurred at the Bronx site. Even though the Brooklyn site usually had the highest average and median concentrations, the Bronx site showed the largest range of values between the 16th and 84th percentiles on an annual basis and in each quarter; the concentrations at the Bronx site varied over the widest range. The Queens site showed a wider range of concentrations between the 16th and 84th percentiles than the Brooklyn site on an annual basis and during the second and third quarters. Even the Riverhead site in the third quarter had a larger range of concentrations than the Brooklyn site (the Brooklyn site at this time had the highest average concentration shown in Table 2). The $SO_4$ average 24-hour concentrations showed an obvious change with quarter: the highest concentrations occurred in the third quarter, the next highest in the second quarter, the third highest in the first quarter and the lowest concentrations occurred in the fourth quarter.

## Respirable Suspended Particulate Concentrations

The average, median and 16th and 84th percentile values of 24-hour RSP concentrations for the four sites for the year and each quarter are listed in Table 3. There is such a scarcity of information on RSP concentrations in the ambient air that there are no indications of concentrations that might constitute a health hazard. However, because of this lack of knowledge about RSP, Congress[4] has directed that studies of the pollutant and its effects be conducted by EPA. Due to the lack of a reference value for the RSP concentrations, discussions are limited to how they compare to one another.

TABLE 3. AVERAGE 24-HOUR CONCENTRATIONS, RSP ($\mu g/m^3$) AND PERCENTILES (16TH/50TH/84TH), CHAMP STATIONS, NEW YORK CITY AREA, JULY 1974-FEBRUARY 1976

| Period of Year | Station | | | |
|---|---|---|---|---|
| | Riverhead | Queens | Brooklyn | Bronx |
| Annual Average | 24 | 32 | 32 | 37 |
| Percentiles | 12/22/36 | 17/29/47 | 17/29/46 | 18/34/55 |
| 1st Quarter Average | 22 | 28 | 29 | 33 |
| Percentiles | 10/20/31 | 14/26/40 | 15/27/39 | 16/29/49 |
| 2nd Quarter Average | 21 | 30 | 28 | 35 |
| Percentiles | 12/21/30 | 18/30/40 | 18/28/38 | 17/31/48 |
| 3rd Quarter Average | 29 | 37 | 35 | 42 |
| Percentiles | 16/26/41 | 18/33/54 | 19/32/52 | 23/40/60 |
| 4th Quarter Average | 22 | 31 | 32 | 36 |
| Percentiles | 10/21/30 | 12/29/45 | 16/30/45 | 15/32/55 |

The average concentrations for the year and in each quarter (Table 3) show that Riverhead had the lowest and the Bronx had the highest RSP concentrations. The average RSP concentrations at the Queens and Brooklyn sites were practically the same at all times and these were generally 5 or 6 $\mu g/m^3$ less than those at the Bronx site. The average concentrations for the

quarters show that the third quarter had the highest concentrations at all four sites. At the three New York City sites the fourth quarter had higher average concentrations than the first and second quarters. The Bronx had the largest range of concentrations between the 16th and 84th percentiles on an annual basis and in each of the quarters. The relatively small differences between the Queens and Brooklyn sites in average percentile concentration indicate that distributions at these two sites were similar at all times of year.

### Distributions of Total Suspended Particulate, Sulfate, and Respirable Suspended Particulate

The average concentrations in Tables 1, 2, and 3 are higher than the median concentration in practically all cases. Furthermore, in all three tables the range of concentrations between the 16th percentile and the median is nearly always less than that between the median and the 84th percentiles. Both of these comparisons demonstrate that the distribution of each of the pollutants - TSP, $SO_4$, and RSP - are not normal. While reducing the distribution arrays of the three pollutants to normal distributions would provide data for more detailed analyses, this reduction was not attempted because recent evidence[5] has shown that determining such a normal distribution is frequently a major undertaking; Whitby[5] has shown that the distributions of sulfur containing aerosols were characterized by a trimodal model consisting of three additive log-normal distributions.

## SPATIAL AGREEMENT IN CONCENTRATION VARIATIONS

The spatial agreement in TSP concentration patterns among the four sites, determined by calculating the correlation coefficients of the daily observation at pairs of sites, is shown in Table 4. Since there were obvious differences among the quarters of the year in the concentrations (Table 1), quarterly as well as annual correlation coefficients were calculated. The annual summary shows that the correlation coefficients among the paired sites ranged from 0.67 to 0.74; the variance explained by one variable in place of the other among the four concentrations patterns

TABLE 4. CORRELATION COEFFICIENTS OF TSP CONCENTRATION ($\mu g/m^3$), NEW YORK CITY STATIONS, JULY 1974-JUNE 1976

| Station | Queens | Brooklyn | Bronx |
|---|---|---|---|
| | | Annual Average | |
| Riverhead | .71 | .72 | .70 |
| Queens | | .74 | .67 |
| Brooklyn | | | .71 |
| | | 1st Quarter | |
| Riverhead | .65 | .56 | .63 |
| Queens | | .67 | .57 |
| Brooklyn | | | .62 |
| | | 2nd Quarter Average | |
| Riverhead | .77 | .81 | .76 |
| Queens | | .74 | .66 |
| Brooklyn | | | .82 |
| | | 3rd Quarter Average | |
| Riverhead | .72 | .71 | .69 |
| Queens | | .77 | .75 |
| Brooklyn | | | .75 |
| | | 4th Quarter Average | |
| Riverhead | .67 | .71 | .70 |
| Queens | | .73 | .73 |
| Brooklyn | | | .66 |

averaged 0.50. On an annual basis, the highest correlation of TSP concentrations was between the closest station, Brooklyn and Queens. However, the poorest correlation was between Queens and the Bronx, not Riverhead and one of the distant sites. The quarterly correlations show that the coefficients changed markedly with time-of-year. The poorest correlations occurred in the first and the best occurred in the second quarter. Generally, the correlations in the second and third quarters were better and those in the fourth and first quarters poorer than the annual correlations. Thus, the correlations were better than average when the concentrations (Table 1) were higher than average. The best correlations occurred in the second quarter between Riverhead and Brooklyn and between Brooklyn and the Bronx. It should be noted that the correlation coefficient for Brooklyn and Queens (the stations with the smallest separation) was considerably less than that for Brooklyn and Riverhead (the pair of sites with the largest separation) in the second quarter; the correlation was not in proportion to the separation of the stations.

The spatial agreement in $SO_4$ concentration patterns at the four stations is shown in Table 5. On an annual basis the correlation coefficients are very high and markedly higher than those shown in the TSP comparisons (Table 4). The best correlation - 0.93 - on an annual basis was between Brooklyn and Queens. Probably the most significant feature of the quarterly correlations is the high coefficients of the Brooklyn-Queens pairings in all quarters. The indication is that a 10-km separation did not cause much of a difference in $SO_4$ concentrations at any time during the year. The high correlation coefficients between Riverhead and all three City sites in all quarters indicate that the $SO_4$ variations were consistent over most of the area a very large portion of the time; the 125-km separations allowed for differences in actual concentrations (Table 2), but most of the time all of the stations showed the same relative concentrations. Considering the four sites as a group, the highest correlation coefficients occurred in the second and lowest in the first quarter (but there was no coefficient less than 0.74). These high correlations among the paired sites indicate that a $SO_4$ observation from one of these sites was representative of the area

and appear to confirm the deductive reasoning[6] that most of the $SO_4$ comes from the oxidation of sulfurous gases in the atomsphere. These gases were emitted upwind of the New York City area and in the combined processes of oxidation and dispersion became uniformly mixed $SO_4$ by the time they were transported to the New York City area.

TABLE 5. CORRELATION COEFFICIENTS OF $SO_4$ CONCENTRATIONS ($\mu g/m^3$), NEW YORK CITY AREA STATION, JULY 1974-JUNE 1976

| Station | Queens | Brooklyn | Bronx |
|---|---|---|---|
| | | Annual Average | |
| Riverhead | .87 | .88 | .86 |
| Queens | | .93 | .85 |
| Brooklyn | | | .86 |
| | | 1st Quarter Average | |
| Riverhead | .82 | .81 | .74 |
| Queens | | .89 | .75 |
| Brooklyn | | | .77 |
| | | 2nd Quarter Average | |
| Riverhead | .94 | .93 | .88 |
| Queens | | .97 | .89 |
| Brooklyn | | | .90 |
| | | 3rd Quarter Average | |
| Riverhead | .85 | .88 | .88 |
| Queens | | .92 | .85 |
| Brooklyn | | | .87 |
| | | 4th Quarter Average | |
| Riverhead | .80 | .86 | .84 |
| Queens | | .92 | .82 |
| Brooklyn | | | .86 |

The spatial agreement in RSP concentration patterns at all four stations is shown in Table 6. On an annual basis, particularily when these correlation coefficients are compared to those for TSP and $SO_4$, the correlations are poor. The best correlation was between the closest stations, Brooklyn and Queens, but this was only 0.60. The overall indi-

cation of these annual coefficients is that the concentration patterns were highly variable and that a RSP measurement represented a very small area. The seasonal correlations show that there was a marked change with time of year. The best correlations occurred for the most part in the third quarter and the poorest generally occurred in the first quarter.

TABLE 6. CORRELATION COEFFICIENTS OF RSP CONCENTRATIONS ($\mu g/m^3$), NEW YORK CITY AREA STATIONS, JULY 1974-FEBRUARY 1976*

| Station | Queens | Brooklyn | Bronx |
|---|---|---|---|
| | Annual Average | | |
| Riverhead | .55 | .49 | .54 |
| Queens | | .60 | .59 |
| Brooklyn | | | .56 |
| | 1st Quarter Average | | |
| Riverhead | .25 | .30 | .39 |
| Queens | | .45 | .55 |
| Brooklyn | | | .51 |
| | 2nd Quarter Average | | |
| Riverhead | .51 | .50 | .63 |
| Queens | | .59 | .68 |
| Brooklyn | | | .58 |
| | 3rd Quarter Average | | |
| Riverhead | .66 | .59 | .68 |
| Queens | | .68 | .64 |
| Brooklyn | | | .60 |
| | 4th Quarter Average | | |
| Riverhead | .59 | .43 | .46 |
| Queens | | .53 | .53 |
| Brooklyn | | | .52 |

* No RSP data available after February 1976.

INTERRELATIONSHIPS OF POLLUTANT CONCENTRATIONS AT INDIVIDUAL SITES

The correlation coefficients based on the comparison of daily TSP and $SO_4$ concentrations at the individual sites are shown in Table 7. On an annual basis the correlations coefficients were practically the same

at all sites. The quarterly correlations show that the coefficients of the second and third quarters were generally higher than the annual coefficients. The poorest correlations occurred in the first quarter, generally a period with low concentrations of TSP (Table 1) and $SO_4$ (Table 2). Riverhead showed the extremes in correlation; the highest of all coefficients occurred at Riverhead in the second quarter and the lowest occurred at Riverhead in the first quarter. The Bronx site showed the most consistency from quarter-to-quarter; the relationship between TSP and $SO_4$ changed very little at the Bronx, the site which generally had high concentrations in every quarter.

TABLE 7. CORRELATION COEFFICIENTS, TSP VERSUS $SO_4$ CONCENTRATIONS, NEW YORK CITY AREA STATIONS, JULY 1974-JUNE 1976

| Period | Station | | | |
|---|---|---|---|---|
| | Riverhead | Queens | Brooklyn | Bronx |
| Annual Average | .77 | .75 | .75 | .85 |
| 1st Quarter Average | .56 | .64 | .70 | .74 |
| 2nd Quarter Average | .84 | .75 | .77 | .79 |
| 3rd Quarter Average | .80 | .82 | .79 | .77 |
| 4th Quarter Average | .72 | .76 | .70 | .79 |

The correlation coefficients based on the comparison of the daily RSP and TSP concentrations at the indivudual sites are shown in Table 8. The annual coefficients are less than those for TSP and $SO_4$ concentrations (Table 7) and show much more variation among the sites. The highest annual coefficient was at the Bronx site, 0.71. The quarterly coefficients showed fairly good correlations in the quarter which had both high RSP and TSP concentrations (Tables 2 and 3); in the third quarter the correlation coefficients were 0.70 or greater. In the first quarter the Brooklyn, Queens, and Riverhead sites showed correlations between RSP and TSP of less than 0.43. The Bronx site showed the most quarter-to-quarter consistency and in the second quarter had a coefficient of 0.85. Riverhead, as it did with the TSP-$SO_4$ comparison, showed the largest quarterly variation, with the third quarter having the highest coefficient and the first quarter the lowest coefficient.

TABLE 8. CORRELATION COEFFICIENTS, TSP VERSUS RSP CONCENTRATIONS, NEW YORK CITY AREA STATIONS, JULY 1974-FEBRUARY 1976

| Period | Station | | | |
|---|---|---|---|---|
| | Riverhead | Queens | Brooklyn | Bronx |
| Annual Average | .65 | .63 | .65 | .71 |
| 1st Quarter Average | .33 | .41 | .42 | .71 |
| 2nd Quarter Average | .74 | .64 | .64 | .85 |
| 3rd Quarter Average | .78 | .70 | .71 | .82 |
| 4th Quarter Average | .61 | .67 | .68 | .61 |

The correlation coefficients based on the comparison of the daily $SO_4$ and RSP concentrations are shown in Table 9. The annual coefficients are comparable to those for RSP versus TSP but lower than those for TSP versus $SO_4$. The highest coefficients, on an annual basis, were at Queens and Riverhead sites but the correlation coefficients were 0.67 or less. The quarterly results were very similar to those for the TSP-RSP comparisons with the second and third quarters showing better correlations than the fourth and first quarters. A second similarity was that the first quarter showed Riverhead, Queens, and Brooklyn had very low coefficients. As with both the RSP-TSP and TSP-$SO_4$ comparison, the Bronx site showed the most consistent pattern through the year and Riverhead showed the largest quarterly variation.

TABLE 9. CORRELATION COEFFICIENTS, RSP VERSUS $SO_4$ CONCENTRATIONS, NEW YORK CITY AREA STATIONS, JULY 1974-FEBRUARY 1976

| Period | Station | | | |
|---|---|---|---|---|
| | Riverhead | Queens | Brooklyn | Bronx |
| Annual Average | .66 | .67 | .61 | .64 |
| 1st Quarter Average | .30 | .33 | .51 | .67 |
| 2nd Quarter Average | .77 | .72 | .61 | .76 |
| 3rd Quarter Average | .81 | .77 | .69 | .73 |
| 4th Quarter Average | .48 | .63 | .56 | .52 |

## SECTION 5

## SUMMARY

On the basis of the statistical analyses of 24-hour concentrations of TSP, $SO_4$, and RSP, the distribution of the concentrations could be characterized as follows:

The TSP concentrations were not normally distributed on an annual basis nor in any quarter of the year. Among the four sites, Riverhead, the site 125 km from New York City, had the lowest average (mean) concentrations on an annual basis and in each quarter. The highest average concentrations in any quarter were at either the Brooklyn or the Bronx site, and on an annual basis the average concentrations at these sites were almost identical. For the year and in each quarter, the Riverhead site showed the smallest range of concentrations and the Bronx site, except for one quarter, had the largest range of concentrations between the 16th and 84th percentiles. Average concentrations of TSP among the four sites were relatively high in the second and third quarters and low in the first and fourth quarters.

The $SO_4$ concentrations were not normally distributed on an annual basis nor in any quarter of the year. Of the four sites, that at Riverhead had the lowest average concentration for the year and in each quarter and the Brooklyn site had the highest average concentration on an annual basis and in three of the four quarters. Even though the Brooklyn site usually had the highest average concentration, all of the other sites in one quarter or another had a larger range of concentrations between the 16th and 84th percentiles than the Brooklyn site. The largest range of concentrations on an annual basis and in each quarter was at the Bronx site. The order of decreasing concentrations among

the quarters was third, second, first, and fourth.

The RSP concentrations were not normally distributed. Among the four sites the average concentrations for the year and in each quarter were highest at the Bronx site and lowest at the Riverhead site. At the Brooklyn and Queens sites, the average concentrations and average percentile concentrations for the year and in each quarter differed very little; the distributions at these two sites were similar throughout the year. The Bronx site had the largest range of concentration on an annual basis and in all four quarters. At the three city sites the fourth quarter average concentrations were higher than those in the first and second quarters.

Spatial correlation analyses of the 24-hour concentrations of the individual pollutants among the four sites showed that:

The concentrations of TSP showed fairly consistent annual correlation coefficients (averaging 0.71) among the individual pairs of sites in spite of the large differences in annual average concentrations among the four sites. The highest correlation on an annual basis was between the closest stations and the two which showed the most similar distribution patterns, Brooklyn and Queens, and not between the stations which observed similar high average concentrations, Brooklyn and the Bronx. The poorest correlation on an annual basis was between adjacent sites in the City, not a City site and the distant Riverhead site; the correlation coefficients did not vary in direct proportion to the spatial separation. The best correlations on a quarterly basis occurred in the second and third quarters, the periods when the concentrations were the highest.

The correlation coefficients for $SO_4$ concentrations between pairs of stations, on an annual basis, ranged from 0.85 to 0.93. This indicates that the correlations were extremely high even though the average concentration at the individual sites differed by as much as 20 percent. The highest quarterly correlations (averaging 0.92) among the four sites occurred in the second quarter, the quarter with the second highest

average concentrations and the second highest range of concentrations between the 16th and 84th percentiles. The third quarter, that with the highest average concentrations, showed correlation coefficients only a little bit better than those for the year. With the exception of the coefficients associated with the Bronx site in the first quarter, all quarterly correlation coefficients between pairs of sites exceeded 0.80. The overall indication was that $SO_4$ concentrations typically increased or decreased on an area-wide basis.

The RSP correlation coefficients on an annual basis ranged from 0.49 to 0.60 between the pairs of stations; these correlations were much lower than those for TSP and $SO_4$ concentrations. On the basis of the distribution patterns shown at the sites this was not anticipated. This is particularly true with regard to the Brooklyn-Queens sites. The RSP distribution patterns for these two stations were very similar yet they show quarterly correlation coefficients as low as 0.49 and 0.53. The overall indication is that in spite of some marked similarities in distribution patterns, increases and decreases in concentrations frequently occurred independently at each site. An RSP measurement appeared to be generally representative of a very small (less than 10 km diameter) area.

The analysis of the interrelationship of the pollutant concentrations, based on the comparison of simultaneous observations of 24-hour concentration of TSP, $SO_4$ and RSP at the individual sites showed that:

The TSP and $SO_4$ concentrations on an annual basis had correlation coefficients that averaged 0.75 at three sites and 0.77 at the Riverhead station. These correlations indicate good agreement. The highest quarterly correlations (averaging approximately 0.79) occurred in the second and third quarters, the two quarters that had relatively high concentrations of both pollutants. In these two quarters the Riverhead site had the best correlations while in the first and fourth quarters the same site had the poorest correlations. The site which showed the most consistency in correlation coefficients from quarter-

to-quarter was the Bronx. The Bronx had the highest annual average TSP and the second highest $SO_4$ concentrations, and usually had the largest range of $SO_4$ and TSP concentrations between the 16th and 84th percentiles in eadh quarter. The correlation coefficients for the comparison of TSP and RSP concentrations were lower and more wide-ranging than those for the TSP-$SO_4$ comparisons; the coefficients at the individual sites ranged from 0.63 to 0.71. Since RSP concentrations appear to depend on local conditions, these correlation coefficients were fairly good. In the first quarter of the year, that with relatively low TSP and RSP concentrations, the coefficients were very low (0.42 or less) at three of the four stations. The most consistent correlations through the quarters were at the Bronx, the site which usually had the highest annual average TSP and RSP concentrations and the largest range of concentration between the 16th and 84th percentiles for both pollutants. The Bronx site had the highest coefficient in the second and third quarters while Riverhead had the second highest coefficients. Since Riverhead had the lowest average concentrations, the coefficients were not proportional to the relative concentrations.

The annual and quarterly coefficients for the RSP-$SO_4$ comparisons at the individual sites were similar in value to those for the TSP-RSP comparisons. Because RSP concentrations tended to depend on local condition, these correlation coefficients were fairly good. The third quarter had relatively high RSP and $SO_4$ concentrations and it showed the best correlations with coefficients ranging from 0.69 to 0.81. The highest coefficient for any quarter occurred at Riverhead in the third quarter; this site had the lowest average concentration in that quarter. The first quarter had shown relatively low average concentrations of RSP and $SO_4$ and the correlations for the period were very low (0.51 or less) at three of the four sites. Again the Bronx site had the most consistency in correlation coefficients from quarter-to-quarter.

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